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MICROPHYSICAL AND OPTICAL PROPERTIES OF CALIFORNIA COASTAL FOGS AT FORT ORD

JUNE 1979

By

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During the period of 12 April through 12 May 1978, the Atmospheric Sciences Laboratory obtained meteorological, optical, and microphysical data in support of the Copperhead optical system performance test under inclement weather conditions. On 3 and 9 May, two well-developed heavy fogs occurred which would seriously degrade the performance of the Copperhead optical system. The first fog was of the advection type and the latter the radiation type but aided by gentle advection. While their synoptic geneses were only briefly touched upon, their microphysical features were examined in greater detail. The radiation fog

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20. ABSTRACT (cont)

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on 9 May contained twice as much liquid water as the advection fog on 3 May although they both had a haze regime. Comparisons were made with other California coastal fogs to draw a general picture of their microstructures. On the basis of limited data, these fogs appeared to share certain common features such as mean and mode radii and liquid water content.

For their optical properties in the visible region, the data points of these two fogs were plotted against Low's generalized or equivalent regression line. About 83 percent of them fall within 15 percent deviation, and all lie within 50 percent deviation. Moreover, the line holds better for the 3 May case than for the 9 May case. Pending further verification, the present study seems to indicate that Low's scaling law may be incorporated as an interim model.

CONTENTS

INTRODUCTION

The Army Combat Development Experimental Command at Fort Ord, California, conducted the Copperhead optical system performance test under adverse weather conditions during the period of 12 April to 12 May 1978. In support of this test, the Operational Test and Evaluation Agency tasked the Atmospheric Sciences Laboratory[1] to provide a description of the meteorological conditions under which the test was to be carried out and directed the Laboratory to compare the meteorological, optical, and microphysical measurements made during the test period at Fort Ord with similar ones at various localities in West Germany to elucidate whether such test results show general applicability. The Fort Ord measurements together with other relevant information may be found in the cited reference.[1]

During this period, thin patchy ground fogs drifted over the test site for short durations occasionally on some days in early morning or late evening hours, but they did not seem to noticeably impair the performance of the Copperhead optical system. However, on 3 and 9 May, two thick fogs occurred in which visibility dropped to a few tens of meters. Of no less interest were their differences in microphysical and hence optical characteristics, not to mention synoptic conditions, although they were both California coastal fogs.

Instead of addressing the problem of comparing these fogs with the German fogs at various localities (which will be dealt with in a subsequent report), it would perhaps be more instructive to examine the microphysical properties of the Fort Ord fogs and compare them to other California coastal fogs since they all share nearly the same synoptic genesis--the wind flow patterns governing these fogs are dominated by the subtropical high off the California coast and to a lesser extent by the inland thermal low during the summer and fall.

The Fort Ord test site is located on the top of a hill, about 300 m above mean sea level (MSL) and about 8 km south of the Monterey Bay shoreline. The nearest town of any consequence is Monterey, about 7 km south of Fort Ord. Monterey is a resort town with very few industries nearby. Los Angeles lies some 400 km to the southeast and the San Francisco Bay area some 80 km to the north. The influence of the latter cannot be overlooked, especially when the flow is northerly. A very informative discussion of

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[1]R. B. Loveland, J. D. Lindberg, J. B. Mason, H. L. Newman, A. F. Lewis, and J. C. Devine, 1978, "Atmospheric Characterization Measurements for Copperhead Ground Fog Experiment, Fort Ord, California," Internal Report, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, 329 pp.

the general synoptic situations conducive to the formation of advection fogs along the California fogs can be found in a report by Goodman.[2]

In view of the modeling requirements in the formulation of the Electro-Optical System Atmospheric Effects Library (EO SAEL), this report shall first examine the microphysics of the Fort Ord fogs in some detail. Then a comparison will be made with the Vandenberg AFB and Los Angeles fogs[3] and with the San Francisco fogs;[2] however, the comparison will be brief and general since their data were not presented in any detail. The optical or extinction properties of the Fort Ord fogs will next be studied in the light of Low's theoretical or generalized regression line[4] governing unimodal and quasi-unimodal drop-size distributions, and the deviations of these fogs will be interpreted. Findings will be discussed, and conclusions will be drawn. Since certain deficiencies were found in the methodology of data collection and presentation in the data report on the Fort Ord fogs,[1] a few afterthoughts will be offered.

MICROPHYSICAL FEATURES OF FORT ORD FOGS

In the past, mechanical droplet impactors have been used by most cloud physicists to collect cloud/fog droplet samples. These devices are not capable of capturing droplets below 1 to 2 micrometers radius because their collection efficiency decreases with droplet size. As a result, the cloud/fog drop-size spectra usually exhibit, on the average, a unimodal or quasi-unimodal shape; and a gamma or lognormal function has often been used to represent them. Mason[5] describes some representative

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[2]Jindra Goodman, 1975, "The Microstructure of California Coastal Fog and Stratus (preliminary report), Report No. 75-02, Department of Meteorology, San Jose State University, San Jose, California, 61 pp

[3]E. J. Mack, W. J. Eadie, C. W. Rogers, W. C. Kocmond, and R. J. Piliė, 1972, "A Field Investigation and Numerical Simulation of Coastal Fog," CAL No. CJ-5055-M-1, Cornell Aeronautical Laboratory (now Calspan Corporation), Buffalo, NY, 136 pp

[4]R. D. H., Low, 1978, "A Theoretical Investigation of Cloud/Fog Extinction Coefficients and Their Spectral Correlations," Beitr. Phys. Atmos. (accepted)

[1]R. B. Loveland, J. D. Lindberg, J. B. Mason, H. L. Newman, A. F. Lewis, and J. C. Devine, 1978, "Atmospheric Characterization Measurements for Copperhead Ground Fog Experiment, Fort Ord, California," Internal Report, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, 329 pp

[5]B. J., Mason, 1971, The Physics of Clouds, London, Oxford University Press, 671 pp

droplet impactors. With the advent of optical particle counters, Hindman[6] observed that a background of smaller particles lying below 1 micrometer radius is invariably superimposed upon the fog drop-size spectra. These are the so-called haze particles. Therefore, it appears that a drop-size spectrum may be arbitrarily separated into two regimes: a stable sub-micron regime consisting of haze particles and an unstable supermicron regime of fog droplets. However, the optical counters are not without their limitations; their upper size limit is often restricted by the individual optical design as well as by the individual aspiration rate or sampling volume the light beam intercepts.

The optical counter used at Fort Ord is Model FSSP-100C manufactured by the Particle Measuring Systems, Incorporated, of Colorado. The counter can collect one drop-size sample every 10 seconds covering droplet sizes of 0.25 to 23 micrometers radius. Note that at this rate of sampling a mountain of droplet data would have been collected during a single fog episode. A cloud physicist interested in the dynamics of cloud/fog evolution may wish to examine the temporal changes of a fog's fine microstructure at 1- to 3-minute intervals. For electro-optical applications, such a fine time interval would serve no useful purpose. Instead, a 5-minute average of 10-second samples is considered to be more than adequate to meet our needs, that is, an average of some 30 individual samples. The following discussion will present the two Fort Ord fogs separately.

The 3 May Fog

The sky was overcast most of the day. In the afternoon, there was a gentle on-shore breeze from the northwest through the northeast at about 5 mps. This northerly flow pattern persisted throughout the fog period, decreasing in speed from about 4 mps when thin, patchy ground fogs formed in low spots along the hillside near midnight (2 May) to about 1.5 mps when the fog lifted with the rising sun near 0700 PDT (Pacific Daylight Time) on 3 May. A weak inversion was reported to be located at about 700 m; however, the fog, which was really low-hanging stratus drifting over the 300 m MSL test site, reached only about 90 m in thickness and stood nearly isothermal. Good droplet samples were taken from about 0116 to about 0600. As a result of the 5-minute averaging procedure, 45 drop-size spectra were obtained during the entire fog episode. Figure 1 is an example of the spectral evolution of this advection fog at nearly 50-minute intervals.

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[6]E. E. Hindman II and O. E. R. Heimdahl, 1977, "Submicron Haze Droplets and Their Influence on Visibility in Fog," preprints: 6th Conference on Inadvertent and Planned Weather Modification, American Meteorological Society, Boston, MA, pp 10-13

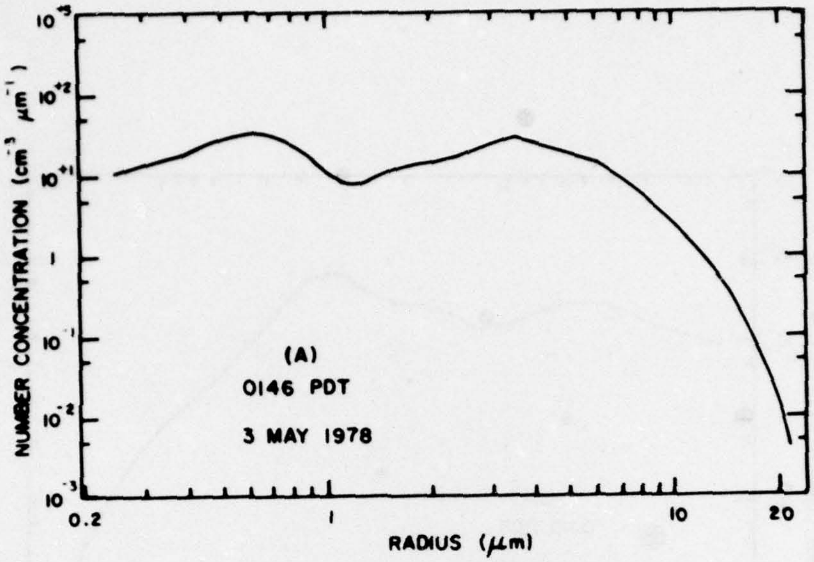

Figure 1A

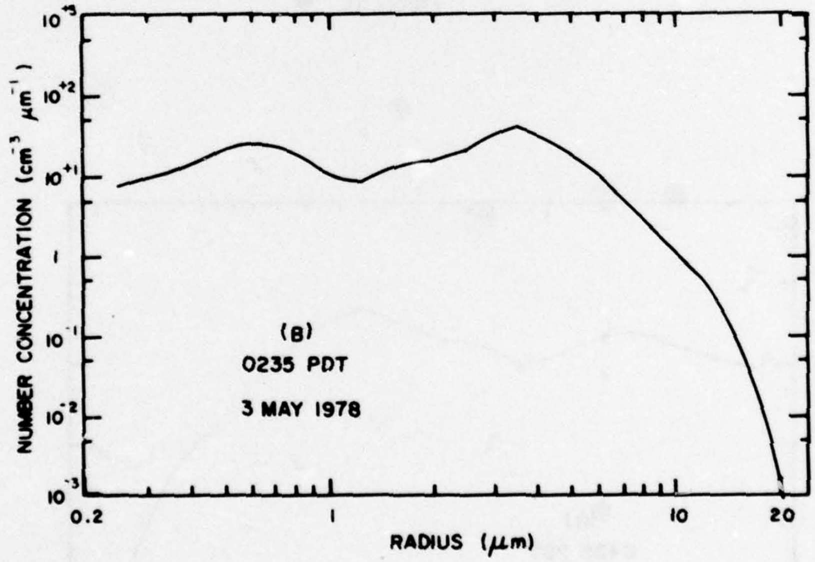

Figure 1B

Figure 1 (A through F). Fog drop-size evolution at about 30 to 40-minute intervals, 3 May 1978.

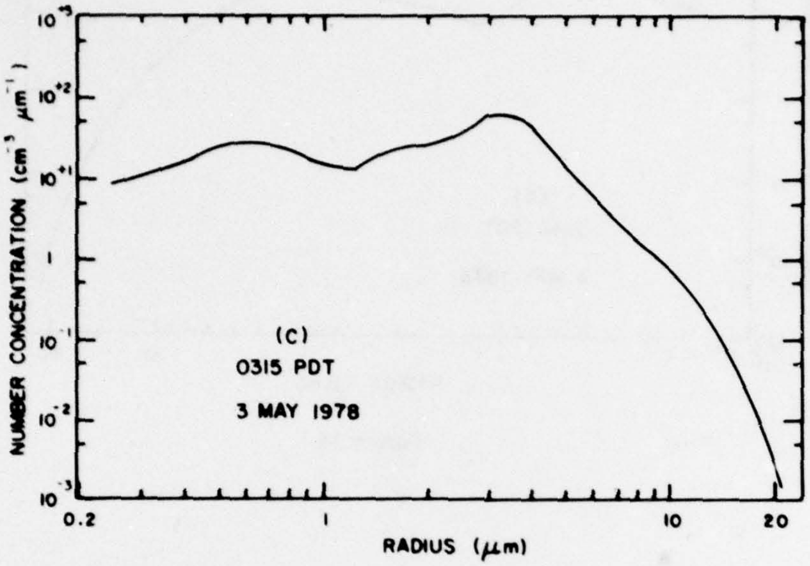

Figure 1C

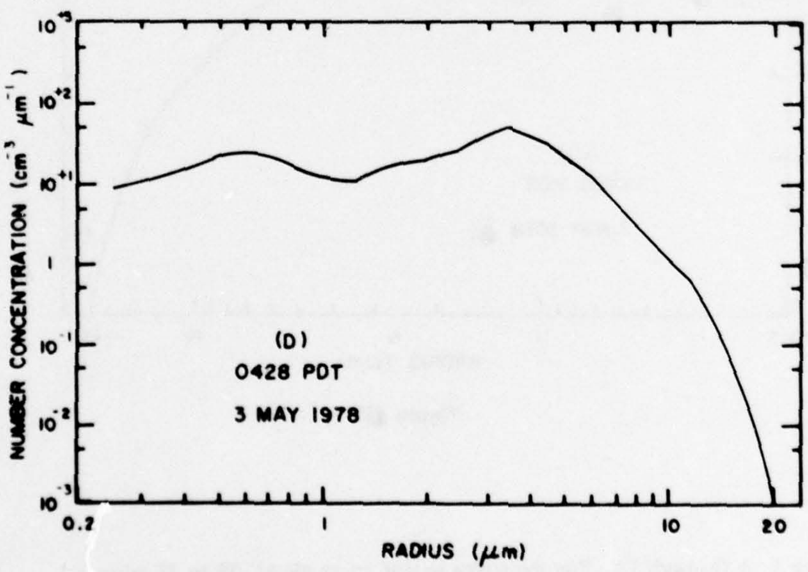

Figure 1D

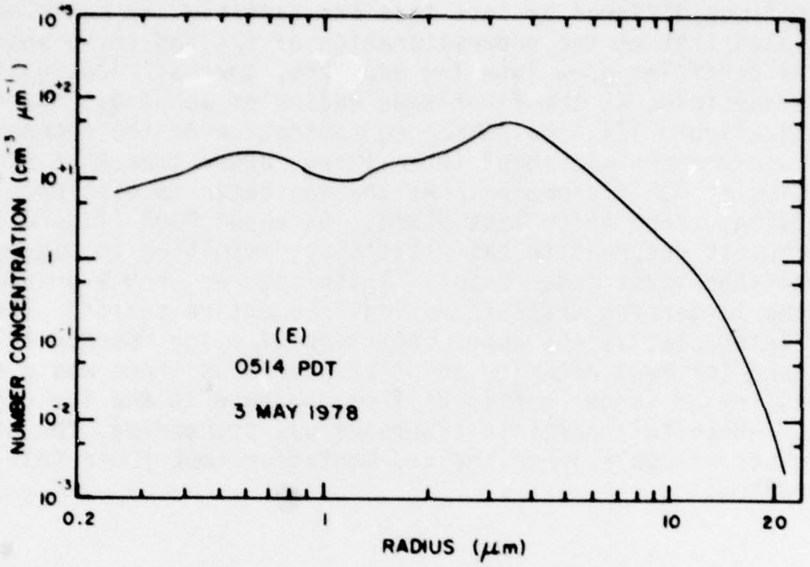

Figure 1E

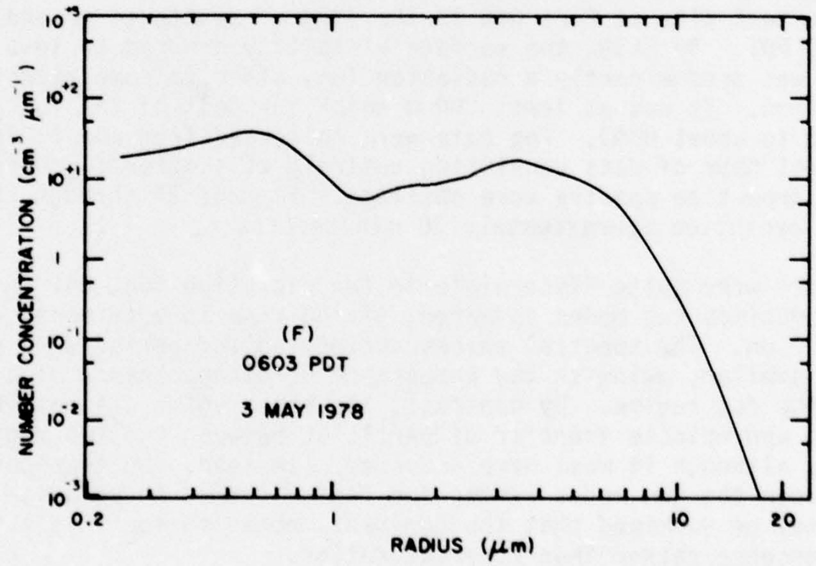

Figure 1F

Two features in these spectra are notable: two distinct regimes and similarity of the spectral shapes throughout the fog period. The mode radii of the two regimes hardly shifted at all; however, upon closer examination, it was discovered that the number concentration of the first mode radius and that of the second fluctuated with time. At the beginning, their concentrations differed by less than one particle per cubic meter. It may be presumed that as the supersaturation of the fog rose, some of the larger haze particles grew into fog droplets, thereby reducing the number of haze particles at the first mode radius of about 0.5 micrometer. At 0514 (figure 1E), the number concentration of the second mode radius at 3.5 micrometers was about three times larger than that of the first mode radius at 0.5 micrometer. As the fog began to dissipate while the sun was rising, evaporation took place. At about 0603 (figure 1F), smaller fog droplets returned to haze particles, resulting in higher concentration of the first mode radius. These figures show a gradual depletion of the larger fog droplets during this entire period. Therefore, one may infer that as the supersaturation of a fog rose or fell in response to cloud (or fog) dynamics and thermodynamics there was a corresponding transfer of larger particles from the haze to the fog regime or vice versa. While this particle transport was proceeding, the microphysical processes of coalescence and sedimentation took their toll of the total concentration.

The 9 May Fog

May 8 was a clear warm day with daytime temperature in the 20's centigrade. The wind varied from calm to a couple of meters per second from the west and persisted through the following day. The inversion extended to about 670 m and the surface moist layer to about 121 m. Fog was first reported in the Monterey-Salinas area shortly after midnight and slowly spread to the test site at Fort Ord in the form of scattered ground fogs to about 0530 PDT. By 0530, the surface visibility dropped to less than 100 m. This fog was predominantly a radiation fog, aided to some extent by gentle advection. It was at least 200 m thick for most of the fog period and persisted to about 0800. Fog data were collected from about 0430 to 0800, the first hour of data consisting entirely of scattered ground fogs. Twenty-three drop-size spectra were obtained. Figures 2A through 2E depict the spectral evolution approximately 30 minutes apart.

The two regimes were quite discernible in the radiation fog, but in the fog regime sometimes two modes appeared, giving rise to a trimodal drop-size distribution. The spectral shapes during the fog period were no longer quite similar, owing to the appearance or disappearance of a second mode in the fog regime. By contrast, the haze regime did not vary too much. No appreciable transfer of particles between the two regimes was apparent, although it must have occurred. Instead, the transport of droplets between the two modes in the fog regime seemed to be quite active. It may be surmised that the dominant mechanism for this activity was coalescence rather than supersaturation.

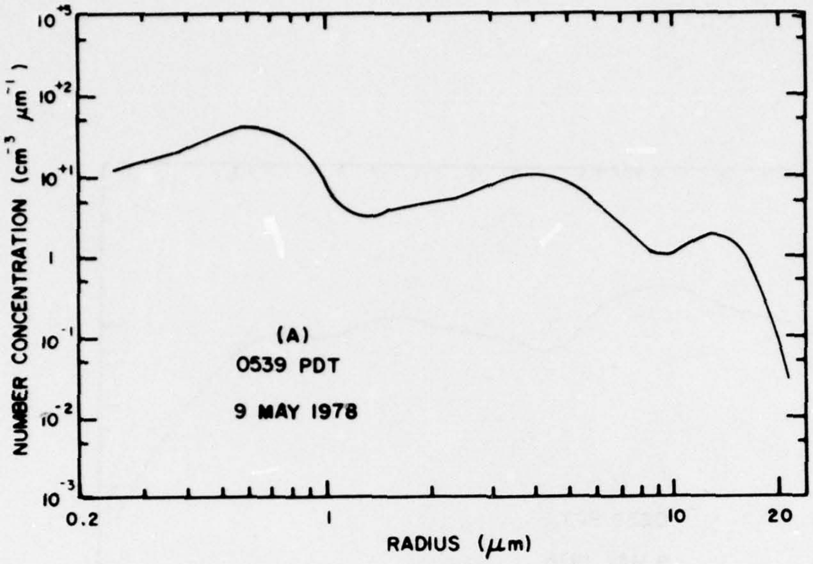

Figure 2A

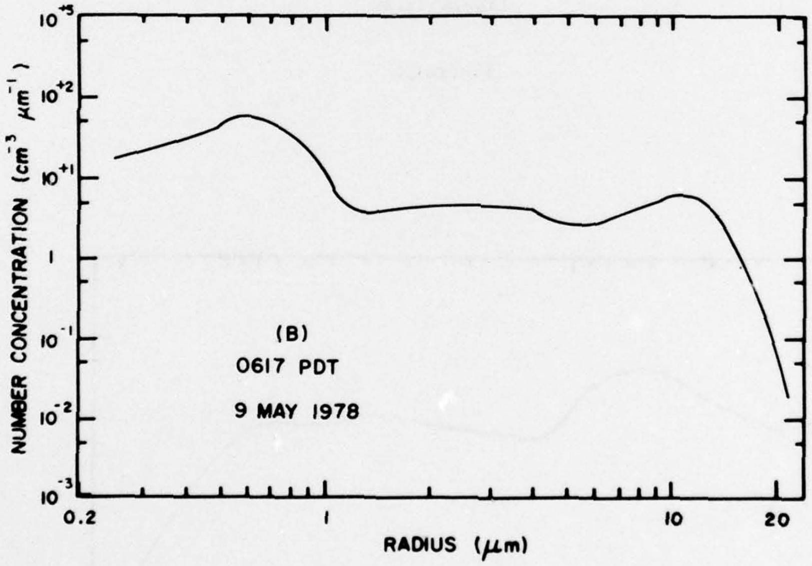

Figure 2B

Figure 2 (A through E). Fog drop-size evolution at about 30 to 40-minute intervals, 9 May 1978.

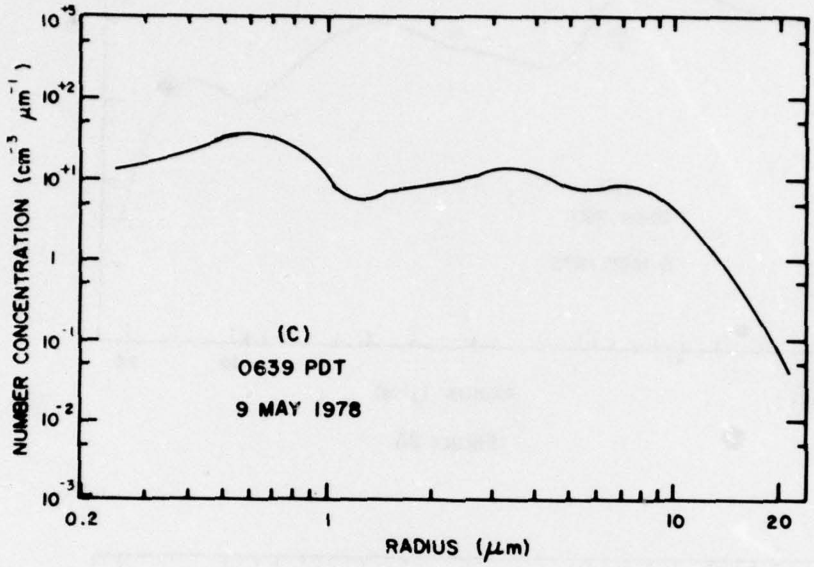

Figure 2C

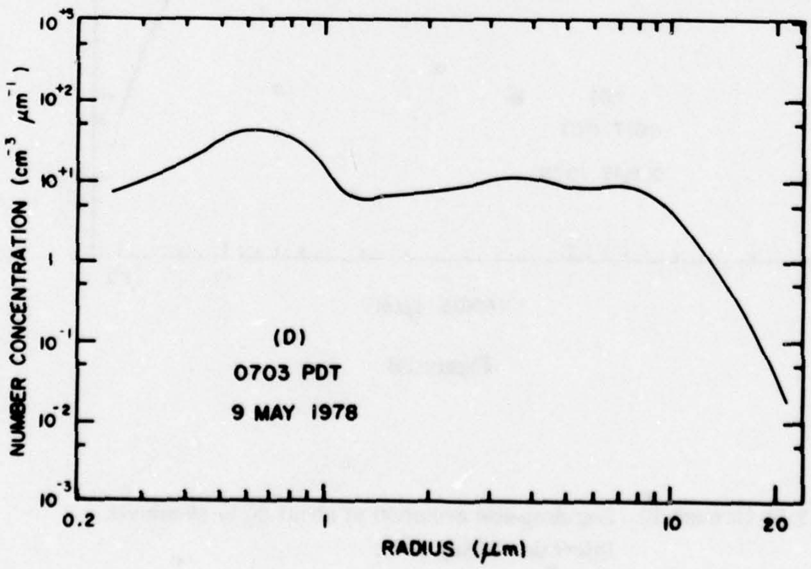

Figure 2D

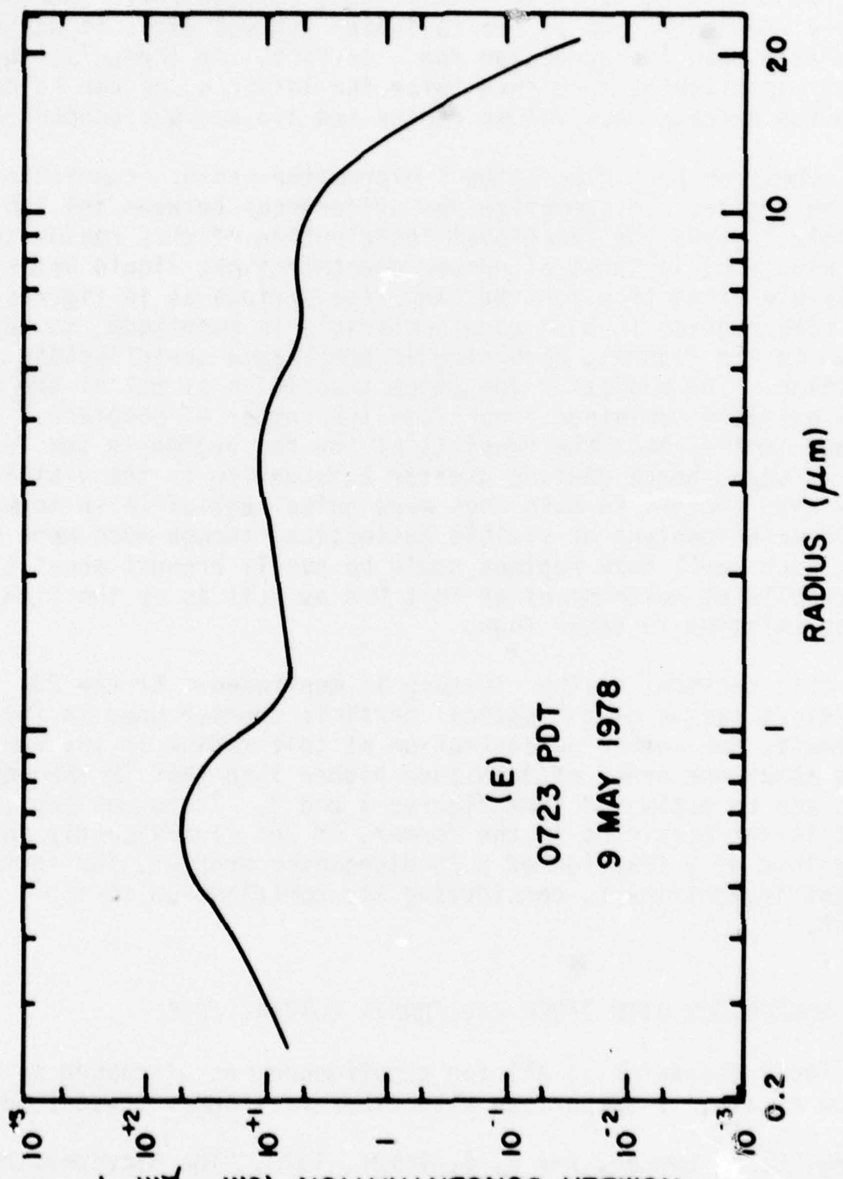
(E)
0723 PDT
9 MAY 1978
NUMBER CONCENTRATION (cm^{-3} μm^{-1})
RADIUS (μm)
0.2
1
10
20
10^{+3}
10^{+2}
10^{+1}
1
10^{-1}
10^{-2}
10^{-3}

Figure 2E

DISCUSSION OF THE TWO FOGS

Although these two Fort Ord fogs came from different origins, they both shared one common characteristic; that is, both had a haze regime in the background which had nearly the same shape and which fluctuated within narrow boundaries, except perhaps during the last period of the 3 May advection fog. In lieu of tabulation, as is usually the practice in the literature, figures 3 and 4 give the mean radius (M), RMS radius (S), mean volume radius (V), and the total number concentration (C) as a function of time, corresponding to the 3 and 9 May fogs, respectively. Moreover, while the total concentration of the radiation fog was less, it was substantially wetter than the advection fog. In fact, the former's liquid water content was slightly more than twice the latter's, as can be calculated from the average mean volume radius and the average concentration.

Assume that submicron particles below 1 micrometer radius constitute the so-called haze regime. To summarize the differences between the two Fort Ord fogs, table 1 gives the fractional contribution of this regime to the total (haze plus fog) in terms of number concentration, liquid water content, and visible extinction for the same time periods as in figures 1 and 2. The haze regimes in both were comparable in magnitude, as may also be noted in the figures, resulting in comparable contributions to total extinction. The radiation fog (more than twice as wet as the advection fog) actually contained a much smaller number of droplets. This smaller number implies that the droplets of the fog regime in the former were larger in size, hence causing greater attenuation in the visible region. The haze sectors in both fogs were quite negligible in terms of either liquid water content or visible extinction, though much more so in the former. Such small haze regimes could be easily brought about by the relatively unpolluted environment at Fort Ord as well as by the high supersaturation existing in those fogs.

To conclude this section, another feature is mentioned. At the 23-micrometer cutoff radius of the optical particle counter used in this field experiment, the number concentration at this radius in the radiation fog was about one order of magnitude higher than that in the advection fog, as can be estimated from figures 1 and 2. There was certainly some loss of larger particles in the former, if not significantly in the latter. The loss of a fraction of a 25-micrometer droplet, for instance, is by no means insignificant, considering its contribution to total liquid water content.

COMPARISON WITH OTHER CALIFORNIA COASTAL FOGS

Despite the local character of all fog occurrences, as discussed at some length by Low et al.,[7] a comparison with other California coastal fogs

[7]R. D. H. Low, L. D. Duncan, and R. B. Gomez, 1978, "The Microphysical Basis of Fog Optical Characterization," ASL-TR-0011, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, 24 pp

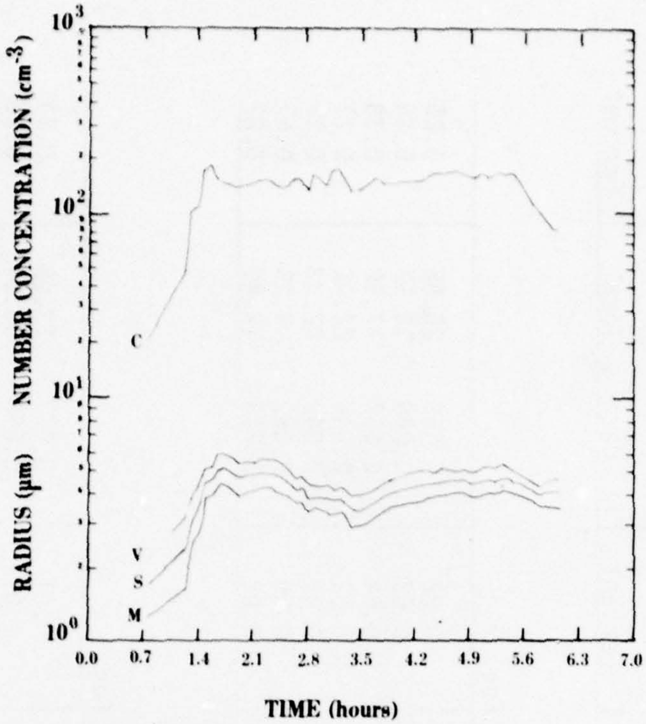

Figure 3. Temporal variations of droplet number concentration (C), mean radius (M), rms radius (S), and mean volume radius (V) in the fog, 3 May 1978.

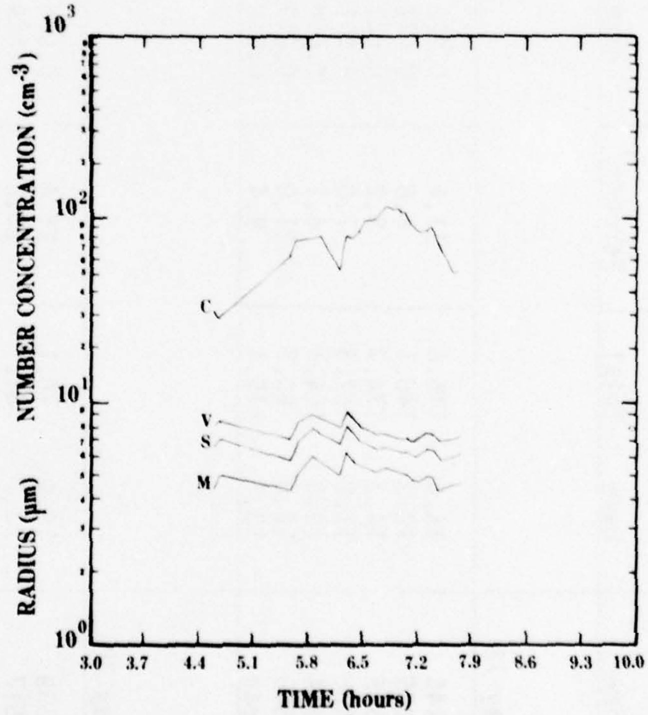

Figure 4. Temporal variations of droplet number concentration (C), mean radius (M) rms radius (S), and mean volume radius (V) in the fog, 9 May 1978.

TABLE 1. FRACTIONAL CONTRIBUTION OF THE HAZE REGIME TO THE TOTAL (HAZE PLUS FOG) NUMBER CONCENTRATION, LIQUID WATER CONTENT, AND VISIBLE EXTINCTION

	Number Concentration (cm^{-3})			Liquid Water Content ($mg\ m^{-3}$)			Visible Extinction (km^{-1})		
Time	Haze	Total	Percent	Haze	Total	Percent	Haze	Total	Percent
3 May 78				Advection Fog					
0146	16.6	145.6	11.4	0.022	123.1	0.02	0.065	25.86	0.25
0235	12.3	140.1	8.8	0.017	75.2	0.02	0.049	18.97	0.26
0315	14.3	174.7	8.2	0.021	58.8	0.04	0.057	17.58	0.33
0428	11.8	167.3	7.0	0.016	83.4	0.02	0.046	22.02	0.21
0514	10.0	164.1	6.1	0.014	90.8	0.02	0.040	22.73	0.17
0603	17.0	80.7	21.0	0.019	33.2	0.06	0.062	9.26	0.67
Mean	13.7	145.4	9.4	0.018	77.4	0.02	0.053	19.40	0.27
9 May 78				Radiation Fog					
0539	19.4	76.1	25.4	0.025	175.8	0.01	0.077	22.98	0.33
0617	23.2	81.7	23.2	0.029	266.4	0.01	0.090	35.04	0.26
0639	16.3	99.8	16.3	0.021	168.9	0.01	0.063	27.28	0.23
0703	21.1	107.1	19.7	0.032	165.6	0.02	0.091	27.89	0.32
0723	20.8	93.9	22.2	0.032	161.4	0.02	0.090	25.15	0.36
Mean	20.2	91.7	22.0	0.028	187.6	0.01	0.082	27.67	0.30

may not be entirely unfruitful. Moreover, such an undertaking may be found quite instructive from either a microphysical or an optical point of view. The advection fogs at Vandenberg, about 250 km south-southeast of Fort Ord, as well as the radiation fogs at Los Angeles examined by Mack et al.[3] and the advection fogs over San Francisco analyzed by Goodman[2] are selected for comparison because they are presented in great detail in their reports. A condensed version of the latter may be found in Goodman.[8] The comparison here will, necessarily, be brief because: (1) both used mechanical impactors for data collection, making it rather laborious, if not impossible, to take droplet samples at frequent intervals, and (2) as a result, descriptions of fine temporal fog microphysical evolution were not available. Therefore, only the average gross features of these fogs were compared with ours.

In terms of condensation nucleus levels, the count at Los Angeles was about 3×10^4, at San Francisco about 6×10^3, and at Vandenberg about 3×10^3 on the average over the duration of field measurements. In terms of cloud condensation nucleus (CCN) at 0.3 percent supersaturation concentrations, the number at Los Angeles was about 2×10^3 and at Vandenberg about 2.5×10^2. Goodman's CCN counter was inoperative. Neither CN nor CCN was monitored at Fort Ord, which was unfortunate since the former would provide some insight in the haze regime and the latter in the fog regime. Table 2 lists a few pertinent parameters for comparison.

In spite of the preceding discussion on instrumentation and local influence, the radiation and advection fogs along the California coast do bear some remarkable resemblance among their respective types in terms of the mean radius, mode radius, liquid water content, and concentration. Except for some indication in Los Angeles fogs where there might be a haze regime, none of the other fogs, because of their measured ranges, showed a haze regime.

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[3]E. J. Mack, W. J. Eadie, C. W. Rogers, W. C. Kocmond, and R. J. Piliè, 1972, "A Field Investigation and Numerical Simulation of Coastal Fog," CAL No. CJ-5055-M-1, Cornell Aeronautical Laboratory (now Calspan Corporation), Buffalo, NY, 136 pp

[2]Jindra Goodman, 1975, "The Microstructure of California Coastal Fog and Stratus (preliminary report), Report No. 75-02, Department of Meteorology, San Jose State University, San Jose, California, 61 pp

[8]Jindra Goodman, 1977, "The Microstructure of California Coastal Fog and Stratus," J. Appl. Meteorol., 16:1056-1067

TABLE 2. A COMPARISON OF CALIFORNIA COASTAL FOGS

Site	Mean Radius (μm)	Mode Radius (μm)	Measured Drop-Size Range	Liquid Water Content ($g\ m^{-3}$)	Concentration (cm^{-3})
Vandenberg (advection)	----	6 - 10	1.5 - 100	0.080	----
San Francisco* (advection)	3.73	3, 5	2.0 - 20	0.044	142.3
Fort Ord (advection)	3.75	0.6, 3.5	0.25 - 23+	0.076	147.4
Los Angeles (radiation)	----	($\leq$1.0) 6 - 10	$\leq$1 - 30	0.170	----
Fort Ord (radiation)	5.11	0.6, 3.5, 11	0.25 - ?	0.156	80.8

*The mean radius is an average of the first three cases, the last one being rejected because it came from a single sample. The mode is an estimate from histograms at the 2 m level.

+The number concentration at 23μm radius falls to the order of 10^{-3} cm^{-3}.

VISUAL EXTINCTION AND LIQUID WATER CONTENT

The foregoing brief discussions of the complex microstructures of the Fort Ord fogs serve to illustrate the difficulties encountered in an attempt to find a unique universal relationship between the liquid water content of a fog and its visibility. Mindful of these difficulties, Low[4] adopted a novel approach by constructing 30 cloud/fog models on the basis of the gamma and lognormal distribution functions of different spectral widths. Considering the extinction at the visible 0.55-micrometer wavelength according to exact Mie calculations,[9] he derived the following generalized regression equation relating liquid water content to extinction for unimodal or quasi-unimodal drop-size spectra with mean radius 3 micrometers and larger:

$$\beta = 93.2\ W^{0.638}\ \mathrm{km}^{-1}\ , \tag{1}$$

where β is the volume extinction coefficient and W liquid water content in g m^{-3}. Although derived from a mixture of the gamma and lognormal distributions of different spectral widths, the relationship between visible extinction and liquid water content may, in fact, be deduced from the usual assumption that the efficiency factor for extinction is 2 in fogs and clouds. Then the extinction coefficient of a single fog particle is given by

$$\beta = 2\ \pi r^2\ , \tag{2}$$

where r is the radius of a monodispersion. It is related exactly to the liquid water content by

$$\beta = 3W/2r\ , \tag{3}$$

from which it follows that

$$\frac{d\beta}{\beta} = \frac{2}{3}\frac{dW}{W}\ . \tag{4}$$

---

[4]R. D. H. Low, 1978, "A Theoretical Investigation of Cloud/Fog Extinction Coefficients and Their Spectral Correlations," Beitr. Phys. Atmos. (accepted)

[9]D. Deirmendjian, 1969, Electromagnetic Scattering on Spherical Polydispersion, New York, Elsevier, 290 pp

The exponent (0.638) in equation (1) differs from 2/3 partly because the cloud/fog models in our theoretical analysis simply did not use 2 as the efficiency factor.

However, the fogs in figures 1 and 2 are not unimodal or even quasi-unimodal. Despite their bumpy appearances, the fog regimes in figure 1 may be considered quasi-unimodal. By contrast, those in figure 2 are not, except perhaps the one in figure 2D. Nevertheless, it would be of interest to find out how the fog data fit Low's theoretical regression line. Figure 5 is a plot of the line together with the data entered at every 5-minute interval. The dashed line on either side of the line represents a 15 percent deviation. Considering the complexities of fog microstructures as well as the nature of the fog data, the 15 percent error bounds set here are quite reasonable. There were 45 and 23 data points, respectively, from the 3 and 9 May fogs. Because of their close proximity, several data points from 3 May lying between the dashed and solid lines were not entered.

Despite the bimodal nature of these fogs, note that a great majority of the points (about 83 percent) are within the error bounds, indicating that Low's generalized relationship can predict the extinction property of the 3 May advection fog at Fort Ord nearly all the time and that of the 9 May radiation fog most of the time (better than 60 percent). It may be recalled from our meteorological analysis that the 9 May radiation fog was not, strictly speaking, a typical radiation fog but one somewhat aided by advection. If one is not averse to a 50 percent deviation, as indicated by the dot-dashed line in the figure, then Low's regression line can predict the extinction properties of both the radiation and the advection fogs at Fort Ord all the time.

Those data points of the 9 May fog which lie beyond the 15 percent deviation line can be readily explained by the fact that their drop-size spectra showed an unmistakable trimodal distribution, as represented by figure 2A. In spite of the bimodality of all the fog samples, the haze regimes given in table 1 apparently were not significant enough to have appreciable effect on their overall optical properties in the visible region. On the other hand, if the haze sector were prominent, as is quite likely in a highly polluted environment, the agreement with Low's theoretical line might not be as favorable.

DISCUSSIONS AND CONCLUSIONS

In this report, the microphysical and optical properties of two different California coastal fogs which occurred at Fort Ord near Monterey have been analyzed. A cursory comparison with other California coastal fogs was made and their similarities noted. Since different droplet sampling devices were used, the haze regime observed in the background of the Fort Ord fogs was not measured by the other investigators. It can be surmised

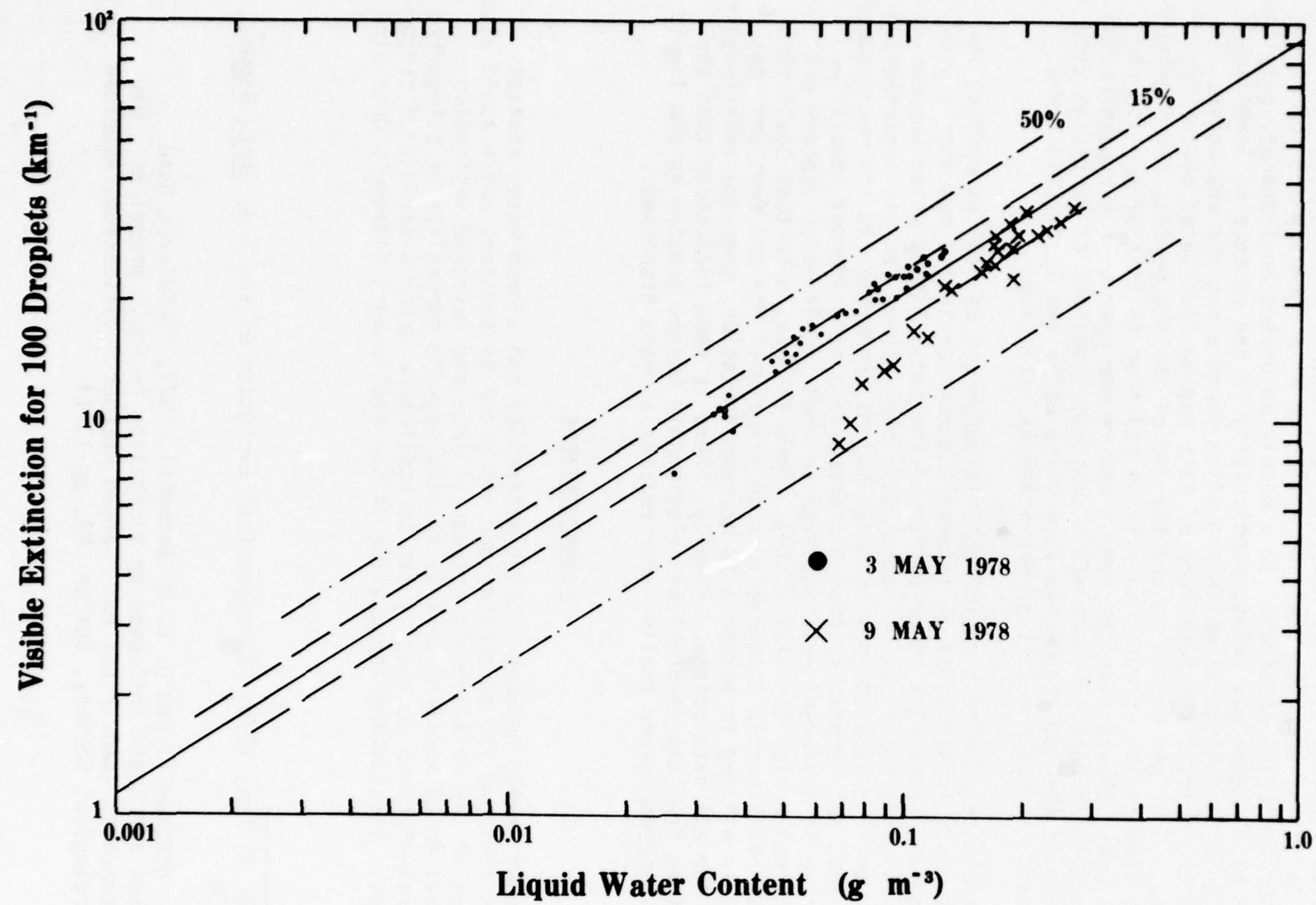

Figure 5. Fog extinction and liquid water content data plotted against Low's theoretical regression line.

that such a regime would be found in many fogs to a greater or lesser extent, depending upon the state of pollution at a locality and the degree of supersaturation attained. In a barely saturated environment, only the stable haze regime may exist, particularly in the absence of large sea-salt condensation nuclei which are often found along the sea coast. In the Fort Ord fogs, the magnitude of this regime fluctuated as the fog evolved. Near the beginning and the end of the fog period, the magnitude of the haze regime appeared to rise in relation to that of the fog regime. Low[10] showed also the same trend in the case of CCN concentration. During the fog period, there was a constant transport of particles from the haze to the fog regime and vice versa while the larger ones were being depleted as a result of gravitational settling.

The existence of a haze regime has microphysical as well as optical implications. It serves as an internal source and in the meantime a sink for fog droplets. Its contribution to the total liquid water content of a fog is quite small, if not completely negligible; yet its contribution to the total extinction may be quite out of proportion to its magnitude.[6] It is thus not surprising that different fogs at different localities give rise to different relationships between liquid water content and visible extinction (or visibility). Nevertheless, note that Low's theoretical relationship appeared to hold quite well for the Fort Ord fogs. If one is willing to accept a 50 percent deviation, then the relationship holds for all data points. Finally, there is some indication that the departure from the theoretical relationship became greater as the liquid water content became smaller--for reasons already discussed.

RECOMMENDATIONS

The relationship between visible extinction and liquid water content varies from one fog to another and one place to another, which would also be true of the relationship between visible and infrared extinctions. The goal in EO modeling work is to find ways to generalize or categorize this relationship so that it may be applicable under a variety of circumstances. Considering the quality of the Knollenberg counter's drop-size

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[10]R. D. H. Low, 1975, "Microphysical Evolution of Fog," J. Rech. Atmos., 2:23-32

[6]E. E. Hindman II and O. E. R. Heimdahl, 1977, "Submicron Haze Droplets and Their Influence on Visibility in Fog," preprints: 6th Conference on Inadvertent and Planned Weather Modification, American Meteorological Society, Boston, MA, pp 10-13

measurements, researchers have insinuated (e.g., Cress and Fenn[11]) that relative error in number concentration may reach as high as 50 percent. Therefore, any relationship derived from the Knollenberg data alone must be expected to incur an error as much as 50 percent. According to private conversation with Dr. G. Hänel, an atmospheric model (unless custom-made) can do no better than predict the mean conditions; thus a model may be considered quite respectable if its relative error is no worse than 50 percent all the time. Nevertheless, the authors of this report feel that the situation may be improved somewhat, and hence the following recommendations.

1. To serve as a cross-check on the Knollenberg data, an accurately calibrated EG&E forward scattering meter should be placed side by side with the Knollenberg counter so that the measured extinction may be compared with the calculated one, thereby lending some confidence to the derived relations.

2. An additional cross-check may be accomplished through the use of the haze particle, the CCN and the CN or Aitken particle counters. The last device will furnish information on the state of pollution at a place, the second on the concentration of particles which may contribute to haze as well as fog formation, and the first on haze formation only. These counters should be operated continuously during a field trip. The data so obtained will throw some light on the fog/haze conditions to be expected at that place. The following table extracted from the report by Mack et al.[3] may illustrate the importance of these measurements.

	Haze Particles (cm^{-3}) Relative Humidity (%)			CCN (cm^{-3}) Supersaturation (%)		CN (cm^{-3})
	97	99	100	0.3	1.0	
Vandenberg	25	35	40	250	630	0.3×10^4
Los Angeles	310	370	580	1800	2800	2.9×10^4

[11]T. S. Cress and R. W. Fenn, Ed., 1978, "OPAQUE Aerosol Counter Intercomparison," 25 April 1977 - 4 May 1977, AFGL-TR-78-0004, USAF Geophysical Laboratory, Hanscom Air Force Base, MA, 56 pp

[3]E. J. Mack, W. J. Eadie, C. W. Rogers, W. C. Kocmond, and R. J. Pilié, 1972, "A Field Investigation and Numerical Simulation of Coastal Fog," CAL No. CJ-5055-M-1, Cornell Aeronautical Laboratory (now Calspan Corporation), Buffalo, NY, 136 pp

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